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Biochar Job Estimating Handbook

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- Biochar is good for soil
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Part II. Biochar Job Estimating

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About Kelpie Wilson:

Kelpie Wilson is an engineer and analyst with 30 years of experience in renewable energy, sustainable forestry and resource conservation. As a consultant, Kelpie works directly with forest managers, farmers and conservationists to develop systems for making biochar from waste biomass. She researches and teaches techniques for using biochar in compost and manure management, and presents many biochar workshops each year. She also grows piles of food every year in a garden shared with neighbors. See more about her work at WilsonBiochar.com

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Part I. Biochar Basics

You may be wondering....

What is Biochar?

Biochar is charcoal that is made from biomass (like wood or straw) by applying heat in the absence of oxygen. Heat bakes the biomass, releasing flammable gasses and leaving behind a solid carbon structure - charcoal. Charcoal that is well-cooked so that harmful tars and oils are no longer present, is easy to use in soil. It absorbs and holds water, air and nutrients, making them available to plants. Biochar is charcoal that is compatible with living systems like soil.



The History of Biochar

In the Amazon rainforest, people added biochar to soils over many thousands of years to help grow food crops in the poor tropical soils. Tropical soils can grow giant rainforests, but when the forest cover is removed, rain washes the soil away. Biochar helped people stabilize and condition the soil for agriculture. Some of the biochar is still there, thousands of years later.

Before the development of modern agricultural technology, farmers in Japan, China, Europe, Africa and many other regions, including the United States, used biochar. Farmers wrote about the benefits of charcoal in the first scientific agriculture journals that were published back in the 1800s:

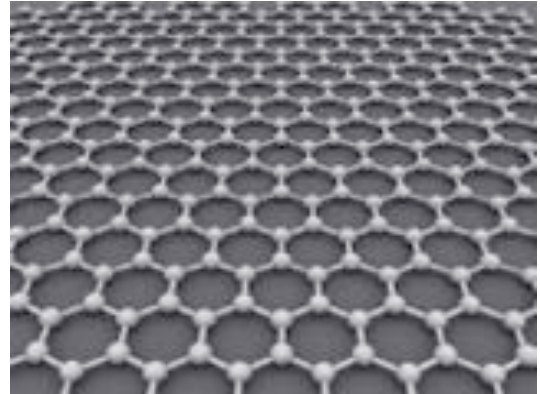
“For two years past I have used some fifty loads each season of refuse charcoal, and being fully convinced that it pays, I wish to recommend it to my brother farmers.”

-- The New Jersey Farmer, September 1856

The benefits of charcoal in soil were once widely recognized by farmers in cultures all around the world, but access was limited and with the advent of cheap fertilizer made from fossil fuels, the biochar tradition was lost.

Biochar is good for soil

Biochar is like permanent compost - a source of soil carbon that supports soil life, but unlike compost, it does not break down quickly. Compost may last for several years in your soil, but biochar will last for decades or centuries. Think of biochar as the “bones” of soil. At a microscopic level, biochar is formed from fused carbon rings that are very stable. This carbon ring structure forms a scaffold that nutrients and minerals hold on to so they stay in the soil where plants can find them. Humus molecules have a backbone of fused carbon rings, and biochar is a seed that starts the process of humus formation



Biochar is like the “bones of soil”. It adds stable structure to soil mineral and organic matter.

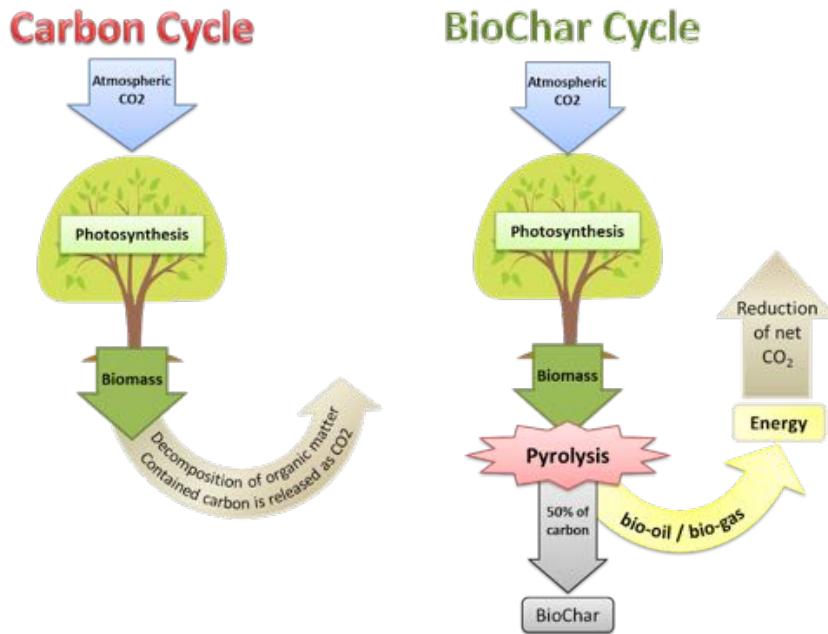
Biochar is a Climate Solution

Plants pull carbon dioxide out of the air when they grow and use it to build plant tissues. When plants die, the carbon returns to the atmosphere. If you convert part of a plant’s carbon to biochar and put it in the soil, you are reducing the amount of carbon dioxide in the atmosphere. This is called Biochar Carbon Capture. But be careful, your biomass must be sustainably grown and harvested and your biochar production process must be clean, or you might make more carbon dioxide than you bury as biochar.

The process of making biochar releases energy. It is a form of burning or thermal conversion without oxygen that is called pyrolysis. If you can use that energy to substitute for energy from fossil fuels, that is another way that biochar can reduce carbon in the atmosphere. For instance, you could use a stove that makes biochar to cook dinner instead of a gas or electric stove. You could use a furnace that makes biochar instead of an oil furnace to heat your home. Today, biomass power plants in the Pacific Northwest are producing biochar, heat and electricity.

If we do it right, biochar can help stabilize our climate by substituting renewable biomass energy (with biochar carbon capture) for some of the fossil fuel energy we consume. But biochar could be harmful if it is made from unsustainable feedstocks like mature trees. Biochar should be made from residues and waste products. It could also be made from quick growing fuel crops that are grown sustainably on formerly degraded land that needs to be re-vegetated. The goal must be to increase the carbon content of soils and vegetative cover where ever possible. Agricultural practices that deplete carbon in order to grow biofuels would defeat the purpose.

It is also important to make biochar in a way that does not increase emissions. Biochar production has to be done using clean methods that do not make more smoke or methane than would otherwise be produced by those feedstocks. Here in the Pacific Northwest, where I live, we often have to burn or treat woody material that is a fire danger. My goal is to turn that material into biochar, using the cleanest methods possible. Wherever you live, you can probably find some kind of waste biomass that can be turned into biochar, so that less of the carbon in that biomass ends up in the atmosphere as carbon dioxide or methane.



Biochar Carbon Capture. You can do it in your own back yard!



Part II. Biochar Job Estimating

How much biochar do I have?

There are two basic ways to measure biochar quantities – weight and volume. Weight is more accurate, but only if you account for the moisture in the biochar. Biochar holds lots of water, and when it is soaked, water could easily account for half the weight of the biochar.

Drying and weighing biochar is difficult, so we generally use volumes in our recipes. But volume is also complicated by the different particle sizes. A bucket full of big chunks gives you less biochar than a bucket full of fines or granular sized biochar. We generally like to crush our biochar to 1/4" inch pieces or less. There will always be a range of particle sizes in the biochar, because it fractures easily.

If you need to convert between weight and volume, take about a gallon of your biochar and crush it to 1/4" minus. Spread it out on a tarp in the hot sun and get it as dry as you can. Measure out a gallon of the biochar as accurately as you can. Tap the container to get the particles to settle – this is called "tap" density - and weigh it. Make sure to subtract the weight of the container. To get the dry bulk density, divide the weight by the volume.

A typical dry bulk density of biochar made in flame cap kilns is about 7-10 pounds per cubic foot. Some kinds of hard wood, like madrone, are more dense than softwoods like fir, and their biochar will be more dense too.

As you combine biochar with other ingredients to make ferments and composts, you may need to convert from gallons to cubic feet or cubic yards. You might also want to measure the amount of wood you use to make biochar. Here are some handy conversion factors:

Values and Conversion Factors for Working with Biochar

Volume

1 cu yd = 27 cu ft

1 cord (4'x4'x8') = 3.25 cu yd of solid wood

Weight

1 kg = 2.2 lbs

1 US short ton = 2000 lb

Density

Dry density of softwoods = 30 lb/cf

Dry density of biochar = 200 lb/cy

Carbon

% fixed carbon in biochar = 80%

1 ton of carbon = 3.67 tons of CO₂

How much biochar can I make with the wood that I have?

Conversion efficiency is the amount of biochar divided by the amount of wood feedstock. Making biochar is a lot of work, so it is important to make biochar as efficiently as we can so we can maximize the amount we make from a given supply of wood.

When you look at the wood you have available, on your property, or wood that you can bring in from elsewhere, try to make a rough estimate of the volume. If the wood is straight tree boles that can be stacked tightly, you can estimate how many cords you have. A cord is the wood that fits into a space that is 4'x4'x8'. But only about 2/3rds of that volume is filled with solid wood. The rest is air.

It is more difficult to estimate the true volume of slash piles. There is a pile mass calculator available here:

<https://depts.washington.edu/nwfire/piles/>

And this Forest Service report explains how to estimate the mass and true volume of a slash pile:

Wright, C. S., Balog, C. S., & Kelly, J. W. (2009). Estimating volume, biomass, and potential emissions of hand-piled fuels. Gen. Tech. Rep. PNW-GTR-805. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 23 p., 805.

https://www.fs.fed.us/pnw/pubs/pnw_gtr805.pdf

If your wood is dry and not more than 4" in diameter, it should char efficiently in a flame cap kiln. You can expect a wood to biochar conversion efficiency of about 15-22% (measured by volume). Here is an example of how to estimate the biochar you can produce:

Example: Biochar Production Estimating

Wood supply: two cords of pine tree boles cut to 4-foot lengths (all under 4" diameter) and three slash piles that are about 6 feet in diameter and 5 feet tall.

Volume of the boles in cubic yards = 2 cords x 3.25 cy/cord = 6.5 cubic yards

Volume of the slash piles:

- Using the pile mass calculator, choose an ellipsoid shape with W1=6; L1=6; and H1=5.
- Enter number of piles=3
- Choose conifer under Pile Composition
- Chose any number for consumption (for emissions data)
- Click on "add pile group"

Sample data input to Pile Biomass Calculator:



Piled Fuels Biomass and Emissions Calculator

Last updated: 3/26/2014

1. DATA ENTRY MODE: **MANUAL (USE ONLINE FORM)** [Start over/use batch mode] [Help]

2. MEASUREMENT SYSTEM: **ENGLISH**

3. Add Pile Group of Pile Type: ☒ Hand ☐ Machine

Describe this pile group:

Pile group name:

Number of piles:

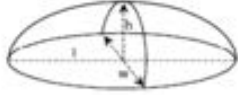
Pile shape: ☐ Half sphere ☐ Paraboloid ☐ Half cylinder ☐ Half-frustum of cone ☐ Cone w/ rounded ends ☒ Half ellipsoid ☐ Irregular solid

Pile dimensions (ft):

W1: W2:

H1: H2:

L1: L2:



Pile composition:

Consumption: % of piled material (Note: Default for Consume = 90%, default for Washington DNR estimates = 85%)

Now you will see the Pile Group Data chart

Pile Group Data: (Click on Group No./Name to edit given group) [Export inputs to text]										
Group No.	Group Name	No. Piles	Pile Type	Pile Shape	Pile Dimensions	Soil %	Packing Ratio	Pile Composition	Pile Quality	Consumption
1	PileGroup1	3	Hand	Half ellipsoid	W1: 6 H1: 5 L1: 6	N/A	N/A	Conifer	N/A	90%
[Remove]										
Done/run calculator Start over (clear all piles)										

Click on Done/run calculator to see your results:

Pile Group Results: [Print-friendly report] [Export results to text]												
Pile Group No.	Pile Group Name	Gross Volume (cubic ft)	Adjusted* Volume (cubic ft)	Pile Biomass (tons)	Consumed Fuel (tons)	Emissions by pollutant (tons)						
						PM	PM ₁₀	PM _{2.5}	CO	CO ₂	CH ₄	NMHC
1	PileGroup1	282.74	278.24	0.6014	0.5413	0.0059	0.0042	0.0037	0.0206	0.9005	0.0015	0.0012
TOTAL		282.74	278.24	0.6014	0.5413	0.0059	0.0042	0.0037	0.0206	0.9005	0.0015	0.0012

The dry mass of the three piles is .6 tons. Now we need to convert back to volume. We assume a dry bulk density of 30 lbs/cf for the pine branches.

1. Convert tons to pounds: .6 tons x 2000 lbs/ton = 1200 lbs
2. Divide by bulk density: 1200 lbs / (30 lbs/cf) = 40 cf
3. Convert to cubic yards: 40 cf / (27 cf/cy) = 1.48 cy

Add the volume of the cord wood to the slash piles and you get:
6.5 + 1.48 = 8.0 cubic yards of wood to char

If the wood is less than 25% moisture, assume a conversion efficiency of 18%:

8 cubic yards of wood x .18 = 1.4 cubic yards of biochar

How long will it take me to make biochar?

Making biochar takes time. It takes time to load the wood slowly into the kilns. It takes time for the wood to heat up in the kiln, for the wood gas to volatilize and burn, and for the remaining carbon to turn into char.

As a rule of thumb, with good, dry fuel, we have found that it takes about 10 minutes to accumulate one inch of char in a flame cap kiln. Smaller brush will char faster, and bigger logs and branches will char more slowly. Wet material is very slow, so dry your feedstock!

The five-foot Oregon Kiln is 24 inches tall and has a volume of 40 cubic feet, which is just about 1.5 cubic yards. At ten minutes per inch of char, it will take 240 minutes to fill the kiln, or 4 hours.

Taking the example above, where we estimate that the 8 cubic yards of wood will produce 1.4 cubic yards of biochar, we can also estimate that one Oregon Kiln can produce that amount of biochar in about four hours.

This estimate of 4 hours to produce one 1.4 cy of biochar does not include the time it took to harvest and prepare the fuel. However, in most cases, that work needed to be done anyway, and if the wood was not going to be made into biochar, it would have had to be chipped or burned to dispose of it (if it is a fire hazard). Chipping and burning also take time, so the additional time to make biochar could be not much more than what you are already doing.

When dealing with hazardous fuels on a property, there is an opportunity to also recover useable firewood. Logs that are greater than 4 inches in diameter are much better used as firewood for heat than for biochar feedstock. In the process of cutting firewood, the smaller logs and branches can be set aside for biochar. Biochar then goes back to the soil on the property, keeping carbon and nutrients onsite.



Morel mushroom grows in biochar scattered in the forest

Biochar Production Job Worksheet

Conversion Factors and Values

Volume

1 cu yd = 27 cu ft

1 cord (4'x4'x8') = 3.25 cu yd of solid wood

Weight

1 kg = 2.2 lbs

1 US short ton = 2000 lb

1 metric ton = 2205 lb

Density

Dry density of softwoods = 30 lb/cf

Dry density of hardwoods = 45 lb/cf

Dry density of biochar = 200 lb/cy

Carbon

% fixed carbon in biochar = 80%

1 ton of carbon = 3.67 tons of CO₂

Alternative Disposal Options

1. _____ \$ cost of chipping/hr ÷ _____ # cy processed/hr = _____ \$/cy to chip
2. _____ \$ cost to haul chips/cy + tipping fee/cy = _____ \$/cy to dispose of chips
3. _____ \$ cost to haul wood/cy + tipping fee/cy = _____ \$/cy to dispose of wood
4. Current market price of bulk biochar: \$125/cy (shipping not included)
5. Wood to biochar conversion efficiency: 18%

Volume Estimates for Sample Job

6. _____ # of cords
7. How much volume in cords: _____ #cords x 3.25 cy/cord = _____ cy cord wood
8. _____ number of brush piles (6'x6'x5')
9. How much mass: _____ # piles x .2 tons/pile = _____ tons slash
10. Convert tons to pounds: _____ tons slash x 2000 lbs/ton = _____ lbs
11. Divide by bulk density: _____ lbs / (30-45 lbs/cf) = _____ cf
12. Convert to cubic yards: _____ cf / (27 cf/cy) = _____ cy
13. _____ cord cy + _____ slash pile cy = _____ total cy wood

Biochar Production and Carbon Sequestration

Determine how much biochar can be produced from a given amount of wood:

14. _____ total cy wood x .18 (conversion efficiency) = _____ cy biochar

Determine carbon sequestration value of the biochar

15. _____ cy biochar x 200 lb/cy (density of biochar) ÷ 2000 lb/ton x .80 (% fixed carbon in biochar) x 3.67 (conversion of carbon to CO₂) = _____ tons of CO₂ sequestered
16. Carbon offset payment/short ton of CO₂: _____ \$ x # tons of CO₂ = _____ \$

Labor Cost of Making Biochar

The five-foot Oregon Kiln is 24 inches tall and has a volume of 40 cubic feet, which is just about 1.5 cubic yards. At ten minutes per inch of char, it will take 240 minutes to fill the kiln, or 4 hours to make 1.5 cubic yards. Allow one hour for setting up and lighting kilns, and allow one hour for quenching and unloading biochar into bags or applying it on nearby landscaping.

On sites where 2 kilns can be used, one worker can fill two kilns at once, doubling the labor productivity.

Labor cost of making biochar, one worker, one kiln:

17. _____ \$ labor rate/hr x 6 hrs ÷ 1.5 = _____ \$ labor/cy

Labor cost of making biochar, one worker, two kilns:

18. _____ \$ labor rate/hr x 6 hrs ÷ 3.0 = _____ \$ labor/cy

Costs and Returns of Onsite Biochar Production

- Feedstock prep needs to follow the 4x4 rule: less than 4' long and less than 4" thick works best in the Oregon Kiln.
- Assume that larger pieces can be sold as firewood which will cover the cost of removing them from the site.
- Assume an additional cost per cubic yard of biochar of 10% to cover additional feedstock prep. Add an overhead cost per cubic yard of biochar of 10% to cover capital equipment and consumables for a total of 20%.

19. _____ \$ labor/cy + (.20 x _____ \$ labor/cy) = _____ \$/cy biochar

20. _____ \$/cy biochar x _____ #cy biochar = _____ \$ total job cost of biochar

21. _____ \$ total job cost of biochar ÷ _____ total cy wood = _____ \$/cy to dispose of wood

Build in a profit margin of 10% per cubic yard of biochar sold to the customer. Determine the total job price. Determine if this will cause "sticker shock" to the customer by comparing your price to the current market price of biochar.

22. _____ \$ total job cost of biochar + (_____ \$ total job cost of biochar x .10) = _____ \$ customer price of biochar

23. _____ \$ customer price of biochar ÷ _____ cy biochar = _____ \$ customer price/cy

24. Compare to current market price: \$125/cy – _____ customer price/cy = _____ \$ savings or price premium

Questions for Further Study

How does your cost of biochar production as a wood disposal method compare with the alternatives?

Can you find someone to pay for the carbon sequestration value of biochar? How will that affect your profit?

If you double the labor productivity of making biochar, how does this affect your profitability?

Can you make a profit if you haul the wood to a burn yard and make biochar there? Add in the cost of hauling, and assume that labor productivity is optimized.

Biochar Production Worksheet – SAMPLE VALUES

Conversion Factors and Values

Volume

1 cu yd = 27 cu ft

1 cord (4'x4'x8') = 3.25 cu yd of solid wood

Weight

1 kg = 2.2 lbs

1 US short ton = 2000 lb

1 metric ton = 2205 lb

Density

Dry density of softwoods = 30 lb/cf

Dry density of hardwoods = 45 lb/cf

Dry density of biochar = 200 lb/cy

Carbon

% fixed carbon in biochar = 80%

1 ton of carbon = 3.67 tons of CO₂

Alternative Disposal Options

1. _____ \$ cost of chipping/hr ÷ _____ # cy processed/hr = _____ \$/cy to chip
2. _____ \$ cost to haul chips/cy + tipping fee/cy = _____ \$/cy to dispose of chips
3. _____ \$ cost to haul wood/cy + tipping fee/cy = _____ \$/cy to dispose of wood
4. Current market price of bulk biochar: \$125/cy (shipping not included)
5. Wood to biochar conversion efficiency: 18%

Volume Estimates for Sample Job

6. 10 # of cords
7. How much volume in cords: 10 #cords x 3.25 cy/cord = 32.5 cy cord wood
8. 17 number of brush piles (6'x6'x5')
9. How much mass: 17 # piles x .2 tons/pile = 3.4 tons slash
10. Convert tons to pounds: 3.4 tons slash x 2000 lbs/ton = 6,800 lbs
11. Divide by bulk density: 6,800 lbs / (30-45lbs/cf) = 226.7 cf
12. Convert to cubic yards: 226.7 cf / (27 cf/cy) = 8.4 cy
13. 32.5 cord cy + 8.4 slash pile cy = 40.9 total cy wood

Biochar Production and Carbon Sequestration

Determine how much biochar can be produced from a given amount of wood:

14. 40.9 total cy wood x .18 (conversion efficiency) = 7.36 cy biochar

Determine carbon sequestration value of the biochar

15. 7.36 cy biochar x 200 lb/cy (density of biochar) ÷ 2000 lb/ton x .80 (% fixed carbon in biochar) x 3.67 (conversion of carbon to CO₂) = 2.16 tons of CO₂ sequestered
16. Carbon offset payment/short ton of CO₂: 50 \$ x # tons of CO₂ = 108.00 \$

Labor Cost of Making Biochar

The five-foot Oregon Kiln is 24 inches tall and has a volume of 40 cubic feet, which is just about 1.5 cubic yards. At ten minutes per inch of char, it will take 240 minutes to fill the kiln, or 4 hours to make 1.5 cubic yards. Allow one hour for setting up and lighting kilns, and allow one hour for quenching and unloading biochar into bags or applying it on nearby landscaping.

On sites where 2 kilns can be used, one worker can fill two kilns at once, doubling the labor productivity.

Labor cost of making biochar, one worker, one kiln:

17. _____ \$ labor rate/hr x 6 hrs ÷ 1.5 = _____ \$ labor/cy

Labor cost of making biochar, one worker, two kilns:

18. 25 \$ labor rate/hr x 6 hrs ÷ 3.0 = 50 \$ labor/cy

Costs and Returns of Onsite Biochar Production

- Feedstock prep needs to follow the 4x4 rule: less than 4' long and less than 4" thick works best in the Oregon Kiln.
- Assume that larger pieces can be sold as firewood which will cover the cost of removing them from the site.
- Assume an additional cost per cubic yard of biochar of 10% to cover additional feedstock prep. Add an overhead cost per cubic yard of biochar of 10% to cover capital equipment and consumables for a total of 20%.

19. 50 \$ labor/cy + (.20 x 50 \$ labor/cy) = 60 \$/cy biochar

20. 60 \$/cy biochar x 7.36 #cy biochar = 441.60 \$ total job cost of biochar

21. 441.60 \$ total job cost of biochar ÷ 40.9 total cy wood = 10.80 \$/cy to dispose of wood

Build in a profit margin of 10% per cubic yard of biochar sold to the customer. Determine the total job price. Determine if this will cause "sticker shock" to the customer by comparing your price to the current market price of biochar.

22. 441.60 \$ total job cost of biochar + (441.60 \$ total job cost of biochar x .10) = 485.76 \$ customer price of biochar

23. 485.76 \$ customer price of biochar ÷ 7.36 cy biochar = 66 \$ customer price/cy

24. Compare to current market price: \$125/cy – 66 customer price/cy = 59 \$ savings or price premium

Questions for Further Study

How does your cost of biochar production as a wood disposal method compare with the alternatives?

Can you find someone to pay for the carbon sequestration value of biochar? How will that affect your profit?

If you double the labor productivity of making biochar, how does this affect your profitability?

Can you make a profit if you haul the wood to a burn yard and make biochar there? Add in the cost of hauling, and assume that labor productivity is optimized.

Practice Guideline: Using a Flame Cap Kiln to Make Biochar

The Flame Cap Kiln method uses a container to exclude air from the bottom and sides of a pile of burning biomass. This guideline covers two types of Flame Cap Kilns:

1. The Oregon Kiln – a steel fire pan with a pyramidal shape
2. The Ring of Fire Kiln – a steel ring with outer heat shield, sealed on the bottom with dirt

These kilns are the designs that we found to be most useful and effective for the forestry situations and feedstocks that we worked with in Oregon. We have made several versions of each type, some designed to break down into sections for easy transport, and some made with heavier steel for moving with a tractor.

There are many other shapes and designs that can work equally well, such as trenches, tubes, cones and simple pits in the ground. Some examples are shown below:

Many Types of Containers Can Be Used as Flame Cap Kilns		
		
The Oregon Kiln	The Ring of Fire Kiln	https://pacificbiochar.com/how-to-make-biochar-with-only-a-match/
		
http://www.thebiocharrevolution.com/blog/biochar-production-in-kon-tiki-australia-1	https://youtu.be/IOSDwp20EKM	http://warmheartworldwide.org/biochar-oven-specs/
For more examples, see BackyardBiochar.net		

This Biochar Practice Guideline was created in 2018 by South Umpqua Rural Community Partnership. Updates available at UBETBiochar.blogspot.com and WilsonBiochar.com. Free to share with attribution.

Flame Cap Kiln Basic 3-Step Method

1. This method starts by building an open pile in the container, lighting it on top, and letting it burn until it collapses and coals begin to form.
2. The operator then switches to a second stage of adding small amounts of new material on top of the coals, one layer at a time, until the container is full.
3. When the kiln is full of hot char, and the flames are gone, it's time to put it out. Either flood it with water, or snuff it with a lid to exclude air.

A Flame Cap Kiln must be continually tended, adding new fuel before the charcoal turns to ash. As each new layer of fuel bursts into flame, the heat transfers by radiation into the partly charred material underneath which continues to char, releasing gasses for the flame. The flame also consumes all the air that might otherwise reach the char underneath. The combination of flame on top and the closed bottom preserves the char until it can be quenched and saved.

Successful biochar production will consider the following factors:

- **Feedstock moisture:** Ideally, moisture content should be below 25%. Wet wood should be tossed aside and not used until it dries out. You will burn up too much wood to create the heat needed to dry the feedstock. A moisture meter for checking firewood costs about \$30.
- **Feedstock size:** ideal size is between 1 and 4 inches thick. If the feedstock is very dry, thicker pieces can be successfully charred.
- **Initial filling of the kiln:** Best practice for lighting is to build an initial rick of medium size material (2" thick is ideal) that is open and loose on the bottom so it can get an air draft as air moves down the sides of the kiln and up from the bottom. The rick should fill the kiln up to about a foot above the kiln rim. On top of the rick of medium size material, place a densely-packed pile of small, very dry brush for kindling. This can be about 12 inches high.
- **Lighting:** Light the kindling and make sure the flame is even across the top. A propane torch is helpful but not necessary if you have dry fuel. Avoid using liquid accelerants.
- **Tending:** Add a new layer of wood when the previous layer begins to show a film of white ash. Try to keep each layer of wood the same diameter so charring is even. Add your biggest material in the middle stages of the burn so it has time to char completely.
- **Finishing:** As the kiln fills with red hot glowing coals, make the last few layers of medium sized material to allow any larger pieces to finish charring. The charring is complete when you no longer see any flames. Don't worry if bigger pieces are not fully charred. After you quench, just set them aside for the next burn.
- **Quenching – with water:** When all the flames are gone, begin adding water in a gentle spray to the top of the kiln. Take care not to use a strong spray because it can drive air into the kiln and force a cloud of black particulates into the steam. You can wear a face mask during this process to protect your lungs from steam and particulates.
- **Double-check your quenching:** Make sure that there is plenty of water. Too little may evaporate and the char can re-ignite. If you don't have as much water as you would like, take the time to stir the char in the water until it is all cool. You should be able to put your hand in it. Or dump the wet char on the ground and spread it thin so it loses heat.
- **Quenching – by snuffing:** An air tight lid can work to quench char. Best practice is to use at least some water to help cool the char. A good lid is a thin sheet of steel placed directly on top of the char layer inside the kiln. Seal the edges with dirt or clay. Cool for at least 12 hours.

Illustrated Guide to Using the Oregon Kiln

Load dry feedstock loosely in the kiln, up to a foot or so above the kiln edge. Nothing should be more than 3 inches in diameter.



Make sure there is dry, kindling size material on the top. Light evenly across the top.



Keeping a flame cap across the top will burn up most of the smoke.



Once the first pile has burned down, start adding more material.



Now that the kiln is very hot, you can add some bigger material.



Some pieces may be too close, cutting off air. Pull them apart with a rake.



When all the flame is gone and ash starts to form, it is time to quench.



Use plenty of water. Too little may result in total evaporation and re-ignition of the char.



Illustrated Guide to Using the Portable Ring of Fire Kiln

Kiln components are lightweight and packable. 	Set up the inner ring and clamp sections together. 
Set up the heat shield. Load the initial charge – loosely packed. 	Light on top. Note: heat shield on blocks for air flow. Pre-heats combustion air. 
Wet quench method uses lots of water. 	Open up the kiln for final quenching. 
Dry quench method – place cap, seal edges with dirt. Check that bottom is sealed too. 	Let it cool overnight before opening. 

CHECKLIST FOR A BIOCHAR BURN – SAFETY FIRST!

Here's a checklist of things you need to consider when planning a biochar burn:

- ☐ Keep a biochar burn log to record your results and promote learning from experience (see included burn log form).
- ☐ You need a water source, both for safety and for quenching the char. Secure your water source before you light the kiln.
- ☐ Even if you are quenching with a lid or with dirt, always have at least five gallons of water on hand for emergencies.
- ☐ Have several shovels and rakes on hand to help control the fire.
- ☐ Make sure flammable materials are cleared from around the kiln. Wet the area if it is dry.
- ☐ Dry wood. A moisture meter is helpful. It's not very efficient to use wood that is more than 25% moisture.
- ☐ Stage your wood nearby. The kiln will use about ten times its volume in feedstock.
- ☐ It is very helpful to sort wood by size ahead of time for efficient layering of similar size material.
- ☐ Safety – All helpers should have leather gloves and wear cotton or wool clothing that won't melt. These piles can put out a lot of heat. Heat exposure for long periods of time is exhausting. Protect yourself and drink plenty of water.
- ☐ Burn only during legal burn days and safe conditions. Get a burn permit as required.
- ☐ Ignition - You can use a propane weed burner type torch for ignition, but all you need is a match if you have plenty of dry kindling. Light it evenly across the top.
- ☐ Make sure the kindling on top is somewhat densely packed so it will sustain a flame and allow the flame to move down to the lower layers. It seems slow to start but pretty soon you'll find the whole pile is ablaze.
- ☐ If you get a lot of smoke, you may be adding too much material at one time. Always keep a strong flame on top of the kiln to burn the smoke.
- ☐ Use a wind screen if conditions are breezy. Even if wind is not a factor, a wind screen will help hold in heat for a safer and more efficient biochar burn.
- ☐ Stop when you are tired, not when the kiln is full. It's ok to fill the kiln, but it's also ok to stop before it is completely full, whether you run out of wood, or just run out of steam.

Tools and Supplies to Have on Hand

- Shovels and rakes
- Water buckets, hoses, nozzles
- Safety equipment: leather gloves, dust masks, eye protection, fire resistant clothing
- Propane torch or matches
- Wrench for installing and removing drain plug
- Chainsaw, hand saw or axe, if needed

Best Practices for Safe Biochar Operations



Wear fire-resistant clothing, and use a heat shield around the kiln.



Keep pets and children away from flames.



Shut off and stow propane torches after use.



Protect yourself from smoke.



Place kilns carefully. Make sure the flame won't torch overhanging tree limbs.



Have your water source ready to go before you light!



For safe and efficient production, place the kiln in a clear open area and stage your feedstocks nearby, but not too close. It helps to sort material by size.

Crushing Biochar



Biochar can be crushed by driving over it with a truck or lawn roller. A small leaf vacuum works fairly well, but a large one is much better, with a more effective and durable impeller for chopping char. You can also use a hammer mill or a roller mill. Be aware that dry char can be very dusty and that wet char can stick and clog machinery. Experiment with moisture levels to find the sweet spot for the equipment that you use for crushing.

Biochar Burn Log – Record Your Results

[illegible]

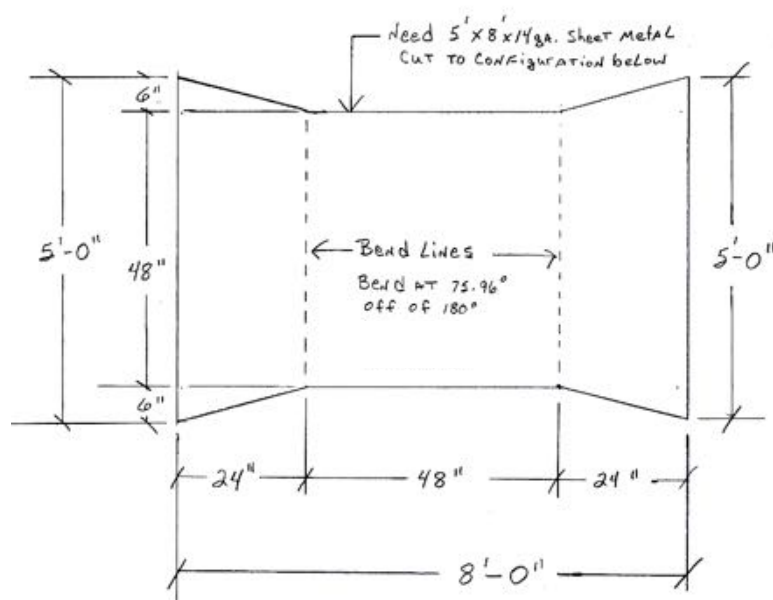
Biochar Kiln Drawings – Oregon Kiln and Ring of Fire Kiln

1. Oregon Kiln – Forestry Size: 5' x 4' x 2'

Oregon Kiln - Bill of Materials for (1) 5'x4'x2' Kiln		
pcs.	Type of Material	Purpose of Material
1	5' x 8' x 14 ga. sheet metal	Kiln body
2	5' x 2' x 14 ga. sheet metal	Kiln sides
4	5/8" dia. Round, 24" long	Handles
1	1/4" x 3 1/2" Flat Bar, 8" long	Corner braces for lift points
4	2" x 2" x 1/4" angle, 5' 6" long	Rim reinforcement
1	1 1/2" pipe coupling, inside threads	Drain hole
1	1 1/2" pipe plug	Drain plug
4	1/2" steel eye hooks and bolts	Lift hooks
Estimated Fabrication Cost – labor and materials (2017 prices)		\$700

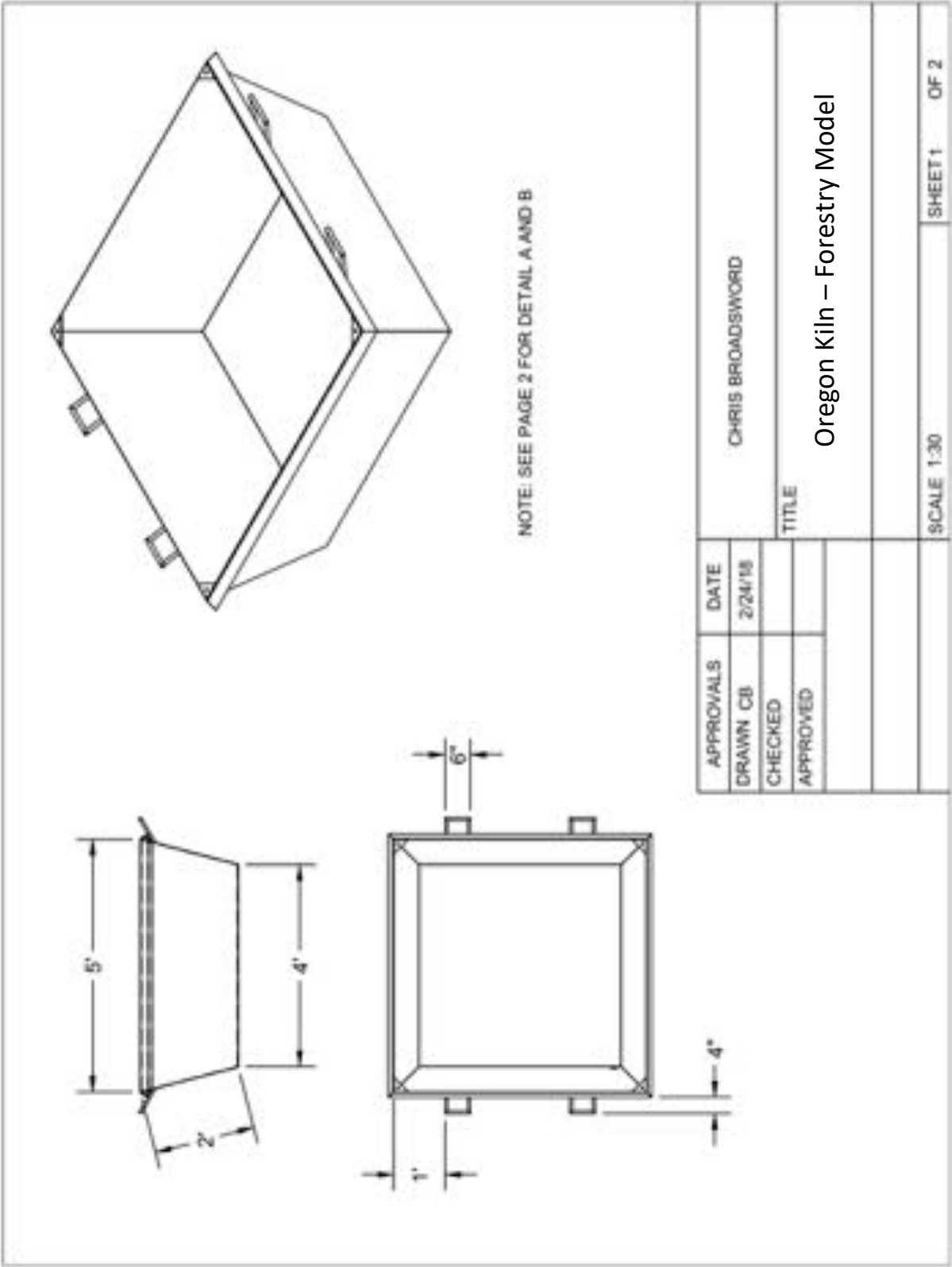
Fabrication Details

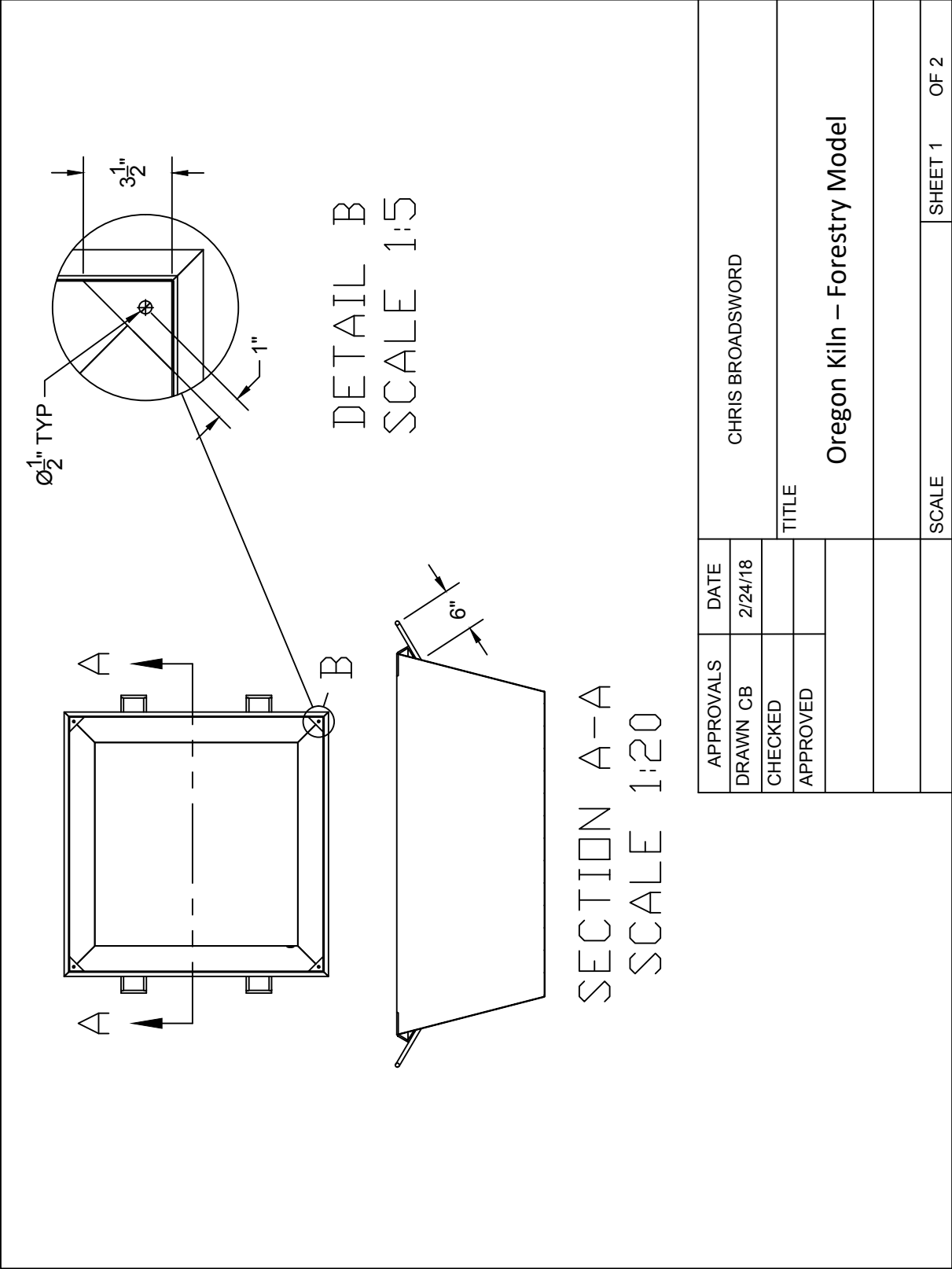
- Cut 5' x 8' sheet as shown and bend. Then weld on side panels for kiln body.
- Or cut panels separately and weld together.
- Drain hole and handle details shown in photograph



Handle and drain hole details of the Oregon Kiln.

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2. Ring of Fire Kiln

Ring of Fire Kiln - Bill of Materials for (1) Kiln and Heat Shield		
pcs.	Type of Material	Purpose of Material
3	44" x 78" x 18 ga. sheet metal	Kiln body
1	77" x 85" 16 ga. sheet metal	Kiln lid
1	18' x 1 1/2" Flat Bar or similar scrap	Kiln lid reinforcement
9	1" Drop Forged Light Duty C-Clamp	Kiln body section fasteners
12	24" x 44" corrugated steel roofing (salvage, free)	Outer heat shield
36	Stainless steel bolts	To fasten roofing sections
5	bricks	To rest heat shield on
Estimated Fabrication Cost – labor and materials (2017 prices)		\$800

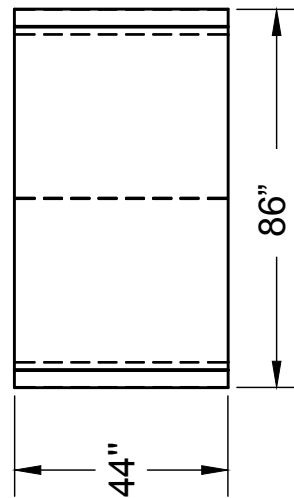
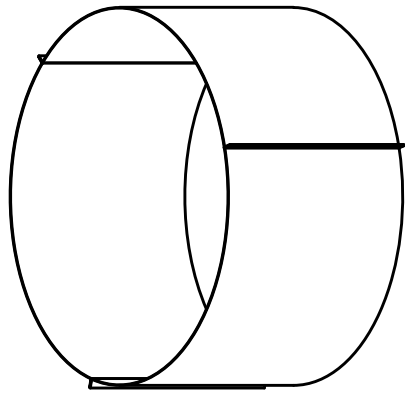
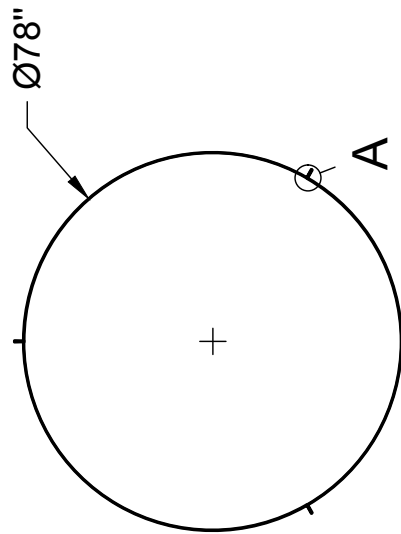
Fabrication Details

- Roll sheet metal pieces to 40" radius and bend flanges for kiln body.
- Cut kiln lid sections to give 4" overlap
- Use scrap roofing for outer ring – drill holes and fasten sheets together with bolts

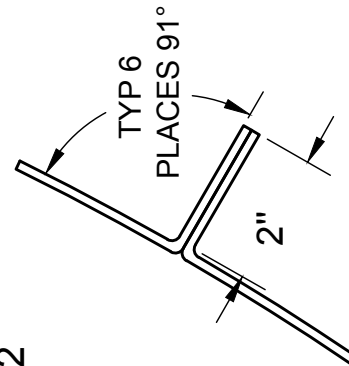


Above left: Use three clamps for each joint. Space clamps evenly.

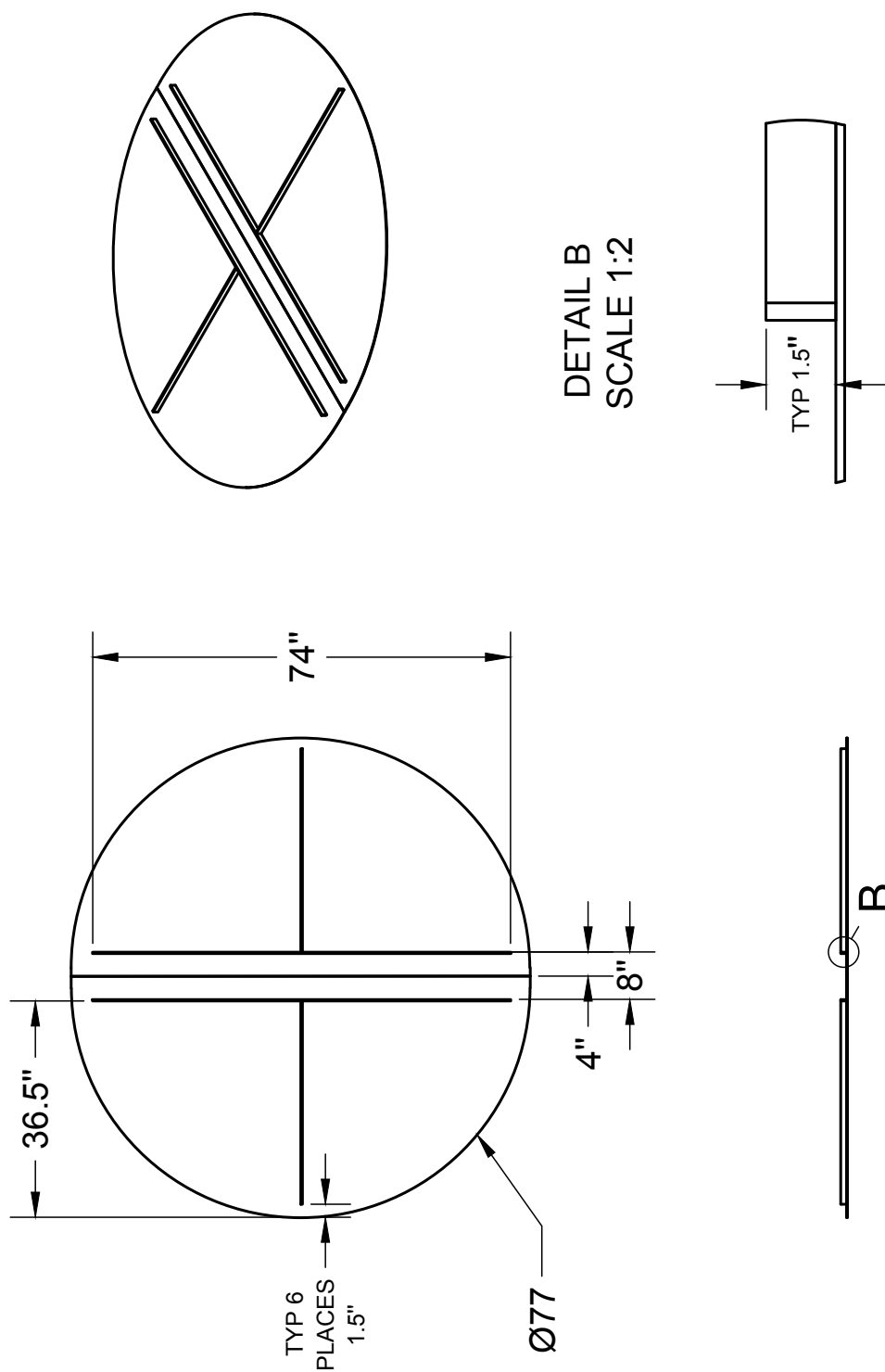
Above right: The kiln lid is in 2 pieces. Place down inside the kiln on top of hot char and make sure that the center sections overlap. Seal the rim with dirt.



DETAIL A
SCALE 1:2



Ring of Fire Kiln – Kiln Body Sections



Ring of Fire Kiln – Kiln Lid Sections

Note: Two piece lid. Place lid pieces separately on top of kiln with 4" overlap.

Practice Guideline: How to Use Biochar in Barns



Why Use Biochar in Barns?

Biochar can do a great job of reducing ammonia and other odors in barns, stables and poultry houses. There are other benefits too:

- Biochar is very effective at capturing nitrogen (N) that is otherwise lost to ammonia volatilization.
- Ammonia creates unpleasant odors in the barn, and harms the respiratory health of creatures who breathe it.
- As ammonia volatilizes, the nitrogen it contains is lost to the atmosphere. If retained, this N could have fertilized fields.
- As N is lost, phosphorus (P) is concentrated in the manure. When manure is applied at the appropriate rate for N, too much P is added to soil where it can leach into groundwater and contribute to environmental problems.
- Along with odor and ammonia reduction, biochar leads to fewer flies and pathogens, for improved animal health.

Biochar can be added to manure after it is cleaned from barns, but by then, it is often too late to maintain the N:P balance because too much N has already been lost. The most efficient process is to use biochar directly in the barn where it can capture nitrogen from urine and manure as it is generated. For even greater impact, biochar can be acidified in order to increase its ability to capture N. See below for some methods to acidify biochar.

How to Use Biochar in Barns

A manure pack in the barn can be managed or unmanaged. An unmanaged pack is simply the accumulation of manure and bedding in the barn that is cleaned out at regular intervals. A manure pack may also be managed to accelerate composting in the barn. Typically this is done by a combination of acidifiers to prevent ammonia volatilization and regular rototilling of the pack to create more aerobic conditions for composting.

There is another, perhaps easier way to degrade manure in the barn that can avoid the work of rototilling. Pioneers in Asia have used a different decomposition pathway to digest manure in barns. This anaerobic pathway is based on lactic acid fermentation, the same process that produces pickles, yogurt and silage. It differs from anaerobic putrefaction by producing organic acids,

alcohols, sugars and other beneficial substances rather than ammonia, hydrogen sulfide and other harmful substances. The process requires moisture control and degradable carbon and it produces a low pH.

Scientists at the University of Hawaii developed a dry deep litter system for pig barns in Hawaii that is based on traditional Korean farming practices. The system uses at least 60 cm of high carbon bedding material mixed with charcoal and cinders. It is inoculated once with indigenous microorganisms (IMO), which include lactic acid bacteria. No tilling or stirring is required. Farmers using the system report healthier animals, almost no odors and no flies. Biochar is an essential part of this self-composting manure pack which can remain in place for up to a decade before cleaning. The lactic acid inoculant also serves to acidify the biochar and increase its effectiveness in absorbing ammonia. Ammonia tends to volatilize at a pH of around 9, yet biochar can have a pH of around 10.

We recommend EM-1 (Effective Microorganisms), a commercially available microbial inoculant that is available from several manufacturers in the US. EM-1 includes a consortium of species along with the lactobacilli. Some of these are facultative anaerobes, that is, they can survive either with or without the presence of oxygen by altering their metabolism. For more information about EM-1, where to get it and how to use it, see the Resource Links below.



Biochar packed into 55 gallon drums is fermented with bokashi (made from wheat bran, EM-1 and molasses) for several weeks, lowering its pH from 9.5 to about 6. The white growth on top is beneficial filamentous bacteria.

A Protocol for Using Biochar in a Dairy Goat Barn

Willow Witt Ranch has a small herd of dairy goats. The goat barn has a manure pack that builds up over several months between cleanings. Along with some straw bedding, goats drop some of their alfalfa feed onto the floor as they eat. We tested two methods of applying biochar to the bedding. Both were effective.

Method #1

- Make biochar and crush to ¼" minus
- To lower pH and inoculate with microbes, prepare 10 gallons of bokashi (wheat bran inoculated with EM-1) and mix with 16 oz. of molasses diluted in two gallons of water.
- Mix bokashi and biochar on a tarp
- Pack mixture into 55 gallon drums to ferment for several weeks
- Sprinkle one 5 gallon bucket of inoculated biochar per 100 sf of barn area, once a week

Method #2

- Make biochar and crush to ¼" minus
- Spread biochar to dry
- Sprinkle one 5 gallon bucket of dry biochar per 100 sf of barn area, once a week
- Use a dust mask while spreading dry biochar
- Make a solution of activated EM-1
- Spray one quart of EM-1 solution per 100 sf on bedding surface, once a week



After six months of adding biochar and EM-1 spray in the goat barn, ammonia odor is gone, even when digging into the pack.

Biochar Is Also Helpful in the Barnyard

If you have outdoor pens and yards with manure that get wet and mucky, use biochar in those areas to help absorb the odors and moisture. No need to crush biochar to small particle sizes as you would for barn bedding, because the animals will crush it with their hooves and mix it with the muck.



Chunky, uncrushed biochar is perfect to add in the barnyard. In this cattle barn, animals have tracked biochar out into the yard where it helps control muck.

Do Your Own Experiments

Every barn is different. Depending on the type and number of animals, the bedding, and other factors, your barn may need more or less biochar to control moisture, odors and pests. Take a look at the resources listed below for more information.

Resources for More Information

General information on biochar in barns:

The Natural Farming Concept: A New Economical Waste Management System for Small Family Swine Farms in Hawai'i: Most Frequently Asked Questions on the IDLS Piggery.

<https://scholarspace.manoa.hawaii.edu/bitstream/10125/33209/1/LM-23.pdf>

Making Waste Our Greatest Resource, by Paul Olivier

<http://www.esrla.com/pdf/landfill.pdf>

Use of Bamboo Charcoal to Remove the Bad Smell of Manure

Food and Fertilizer Technology Center

<http://www.ffc.agnet.org/library.php?func=view&style=type&id=20110801174821>

Biochar: Helping Everything from Soil Fertility to Odor Reduction

<http://ecofarmingdaily.com/biochar-poultry-farming-unexpected-uses-biocarbon/>

Ohio Heifer Center recycles manure, saves \$800,000 on bedding

<https://www.progressivedairy.com/topics/manure/ohio-heifer-center-recycles-manure-saves-800-000-on-bedding>

Information on bokashi, EM-1 and other inoculants:

EM-1 Application Manual – this will tell you how to make activated EM-1 and bokashi

http://www.7springsfarm.com/content/EM1_APPLICATION_MANUAL.pdf

Natural Farming Hawaii – Odorless Pig Technology <http://naturalfarminghawaii.net/learn-natural-farming/odorless-pig-technology/>

An introduction to Asian Natural Farming

<https://www.echocommunity.org/en/resources/d8397abc-c85f-47a8-96a3-a25c6660e3a5>

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Practice Guideline: How to Use Biochar in Compost



The Composting Process

The composting process is governed by various physical parameters that are subject to alteration by the addition of biochar materials as bulking agents. Some of the parameters that most affect compost are: aeration, moisture content, temperature, bulk density, pH, and the absorption capacity of bulking agents. Water is held in biochar pore spaces and voids, and in the spaces between particles. Biochar increases the C:N (carbon to nitrogen) ratio of the compost. Here is a list of different impacts that biochar can have on compost:

- Biochar helps adjust the C:N of high nitrogen ingredients
- Biochar keeps compost moist and aerated
- Compost with biochar may not require turning, or may need less turning
- Biochar increases nitrogen retention
- Biochar improves compost maturity and humus content
- Biochar compost improves plant growth

We have learned that adding biochar to compost must be done with careful reference to C:N ratios. Biochar affects C:N in at least two ways: 1) biochar contains at least some degradable carbon; and 2) biochar absorbs N, making it potentially less available to compost micro-organisms. For best results using biochar in compost, it is beneficial to combine biochar directly with a high nitrogen source and then add to compost with other materials that have good C:N ratios.

When planning a compost project on the farm, it may be helpful to do some small scale experiments first to determine the correct ratio of ingredients for achieving a hot compost using biochar. Here are a few helpful things to keep in mind about biochar:

- C:N of biochar itself could be about 100:1 or greater – it depends on the biochar
- Typically, only about 10-30% of the total C in biochar is available for microbes to consume
- It is important to add enough degradable carbon (such as sugars, cellulose or carbohydrates) along with the biochar to help feed microbes
- Biochar may influence the active C:N by absorbing N
- Biochar may influence the active C:N by promoting rapid bacterial metabolism of N
- Biochar content for good compost ranges from 3%-25% depending on N content of manure, amount of degradable carbon, and other ingredients

How to Set Up a Biochar Compost Experiment

Hypothesis

Biochar will impact compost processes (time and temperature) and compost qualities (maturity, nutrient content, humus content).

Treatments

- Set up one compost with biochar and one compost without biochar (a control treatment).
- If you like, you can replicate the experiment with multiple piles of each treatment
- Pulverize biochar to a size that is mostly ¼" or smaller. Some larger pieces are ok and will help with aeration.
- Apply biochar at between 3% and 25% by volume to the biochar compost
- Use a compost calculator (see Resources) to estimate C:N ratio of compost ingredients

Methods

- Choose a compost container – wire bins, open piles, or fiber sacks
- Construct piles in layers, taking care to add bulk materials and biochar in enough layers to allow natural aeration
- Water both piles the same
- Monitor moisture – it should pass the “squeeze test”
- The Squeeze Test – take a handful of material and squeeze. No water should come out, but when you open your hand, there should be enough moisture to hold the material together so it does not fall apart instantly

Measurements

- Use the provided data sheet for temperature measurements
- Daily temperature measurements for first two weeks (or every other day)
- Weekly temperature measurements for next 4 weeks
- Sample compost after 90 days and send for testing



Make an experimental compost using wire bins, open piles, or 100 gallon compost sacks. Measure your ingredients and mix by layering.

Lab Tests

Temperature measurements will tell you how the composting process compares with and without biochar, but to know how it compares as a fertilizer, you will want to test the results. You should expect to see an increase in retained nitrogen in the biochar compost. You may also see a difference in the indicators for compost maturity. Below are some tests you can request from most soil labs:

- Nutrient profile
- C:N ratio
- Compost stability test (CO₂ respiration)

Plant Bioassay

- Use a plant bioassay to compare soil with and without biochar compost to see what differences the compost makes in plant growth
- For instructions, see the practice guideline: *Plant Bioassays to Evaluate Biochar Compost*

Resources

Fiber Compost Sacks

Even though these only hold 100 gallons (half of a cubic yard) we found that they serve well for compost experiments. The outer edges of the sacks will be somewhat cooler, but if the C:N is right, the middle will heat up to thermophilic temperatures for good composting. You may not want to use these as your regular compost container, but they work very well for experimenting with compost ingredients and recipes. Source of fiber compost sacks:

<https://smarpots.com/compostsak/>

Compost Calculators

Several handy calculators and spreadsheets are available online to help you know the C:N of your compost ingredients and the overall C:N of the ingredients mixed together.

C:N Ratio Compost Mix Calculator

<https://www.klickitatcounty.org/1030/Compost-Mix-Calculator>

Comprehensive Composting Info

<http://compost.css.cornell.edu/science.html>

A Useful Biochar Composting Guideline

Technical Note: Conditioning Biochars for application to Soils by James Joyce BE, Principal Technologist, Black is Green Pty.

https://www.terra-char.com/uploads/2/3/7/9/23790961/composting_with_biochar.pdf

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Compost Pile Temperature Data Sheet

Instructions: Use one data sheet for each pile. Circle the unit you will use: F or C. Before taking pile temperature, read the thermometer dial in air and record ambient temperature. Insert thermometer as close to the center of the pile as you can. Allow at least 60 seconds for the temperature reading to stabilize. Record the temperature. If possible, take a second measurement at a different location in the pile. Make a note about the weather: clear, cloudy, rain or snow.

Units: F or C	Pile Description:			
Date/Time	Ambient Temp	pile location #1	pile location #2	Weather

Practice Guideline: Plant Bioassays to Evaluate Biochar Compost



A Wide Variety of Biochar Composts to Compare

We can make a wide variety of compost preparations and fertilizer mixes with biochar and other organic materials including manure, food waste, crop waste, and organic fertilizers such as seed meal, rock dust, liquid fish and kelp meal. We can compost the ingredients in anaerobic compost piles with balanced C:N ratio that promotes thermophilic (heat-loving) organisms, or we can add ingredients to worm bins, or mesophilic (warm) piles that don't reach thermophilic temperatures. We can also use biochar in anaerobic ferments such as bokashi, or we can simply culture a pile of biochar by adding some nutrients and moisture and allowing native microorganisms to begin consuming nutrients and depositing metabolic products on the surfaces of biochar. These products form organic coatings on the biochar that help determine its benefits to soil fertility (Hagemann et al 2017).

Compost Needs to Mature

All of the above processes take time. During the periods of active metabolism, microbial respiration rates are high and a great variety of unstable or phytotoxic organic compounds are present. These compounds can include ammonia, volatile organic acids, bacterial enzymes, salts and other chemicals that could be toxic to plants, especially seedlings (Woods End Research Laboratory, 2005). This is known as phytotoxicity. Mature compost has broken down these phytotoxic compounds and transformed them into humus, the stable byproduct of microbial metabolism that is beneficial to plant growth. Anaerobic ferments also need to mature before adding to soil because they can acidify soil to the point where it inhibits plant growth.

Compost Can Have Both Nutrients and Toxins

Compost can be tested for nutrient content and availability using soil testing methods. Compost maturity is usually gauged by measuring respiration rate. These tests are done in a lab, yet they will not indicate the presence of phytotoxic compounds. One of the best ways to determine if phytotoxic compounds are present is to perform a plant bioassay.

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Plant Bioassay: the Basics

The plant bioassay we use is a two week germination and growth test using cucumber seeds. The basic procedure is to mix the target material with a plain, peat-based potting soil at the desired rate and plant the same number of seeds in each pot. Trays of pots are placed in a controlled environment and grown for two weeks. At the end of the growth period, we count the number of germinations (a strong indicator of phytotoxicity) and the number of secondary leaves. The number of secondary leaves may indicate different levels of growth promoting hormones, nutrients or other constituents in the target amendment. Then we cut, dry and weigh the biomass of each treatment. The biomass weight will tell us something about nutrients available for growth.

The plant bioassay is primarily used for determining whether a compost material is mature enough to use, but it is also useful for comparing the effects of different amendments on plant growth. A complete protocol is outlined below, followed by an Illustrated Guide with additional information.

Plant Bioassay Protocol for Testing Biochar Compost Materials

Materials needed:

- Plain peat-based potting soil with no added nutrients, such as Sunshine Mix #4 with perlite
- A number of 4 inch round plastic pots
- A package of 16 ounce clear plastic drink cups to use as humidity domes
- Greenhouse trays
- Label, tape and indelible markers
- 1000 milliliter beaker
- 100 milliliter beaker
- Clean bins for mixing soil. We use bus trays from a restaurant supply store.
- Mesh bags. We used a nylon net bath scrubber – unfurl it and it is one long mesh tube that can be cut into sections to use as bags to contain the plants for drying.
- Food dehydrator
- Scale accurate to .01 grams
- Controlled growth environment such as greenhouse or growth chamber

Procedure:

1. Determine number of treatments, plus a control using plain potting soil, and label all pots with treatment code and replication number. Use at least 3 replications. Five is better.
2. Determine treatment rate on volume-to-volume basis (usually 20% treatment to 80% soil).
3. Fill one pot with dry soil and tap the pot gently against the table surface to pack lightly. Weigh volume of soil that fills one pot = **a**.
4. Fill control pots with soil
 - a. Multiply weight **a** times number of replicates (usually 5).
 - b. Weigh that amount of soil and place in bin – this will be soil for control pots.
 - c. Measure a volume of water equal to half the volume of the 5 control pots and mix with soil to moisten. Let stand for 10 minutes, then fill pots.
5. Mix treatment and fill pots with soil-treatment mix (see example, page 6).
 - a. Multiply weight **a** x 80% x # replicates.
 - b. Weigh that amount of dry soil and place in bin.
 - c. Multiply volume of one pot by 20% for treatment volume. For example, if pot volume is 300 ml, then 20% of that volume is 60 ml.
 - d. Multiply treatment volume by # replicates.

- e. Measure the total volume of treatment material into a beaker. Tap to pack lightly. Place total volume of treatment material in bin with dry soil.
 - f. Mix soil and treatment thoroughly.
 - g. Measure a volume of water equal to half the volume of the 5 treatment pots and mix with soil to moisten. Let stand for 10 minutes, then fill pots.
6. Mix additional treatments using same method as 5.
7. Plant seeds.
 - a. Place 10 cucumber seeds from the same packet evenly spaced on the surface of each pot. Keep seeds away from sides of pot.
 - b. Place about ¼ cup of moist, un-amended soil on top of the seeds and press to spread the moist soil evenly across the top of the pot, covering all the seeds with at least 1/8" of soil.
 - c. Add about a tablespoon of additional water to each pot to make sure that soil is completely saturated.
8. Prepare plants for growth chamber or greenhouse.
 - a. Place a humidity dome (plastic drinking cup) on each pot and secure with tape if needed.
 - b. Place pots on trays, randomizing pots within each tray or block.
9. Growth Phase
 - a. Determine lighting schedule and set up timers if using artificial light.
 - b. If growing in greenhouse, supply heat mats, if needed.
 - c. If growing in growth chamber, adjust exhaust fan temperature control as needed.
 - d. Grow plants for 14 days. Do not open humidity domes or add any more water.
10. Evaluate results.
 - a. Count number of germinations in each pot and record.
 - b. Count number of well-formed secondary leaves in each pot and record.
 - c. Count number of incipient secondary leaf buds in each pot and record.
 - d. Take photographs of trays to record information such as leaf color.
 - e. Snip off above ground vegetation at soil level for all of the pots in each treatment (including control) and place in one labeled mesh bag for each treatment.
 - f. Place mesh bags of vegetation in drying oven or food dehydrator and dry for 24 hours at 105 degrees F.
 - g. Remove dried vegetation from each bag and weigh biomass for that treatment.
 - h. Record total biomass for each treatment.

References

- Hagemann, N., Joseph, S., Schmidt, H. P., Kammann, C. I., Harter, J., Borch, T., ... & McKenna, A. (2017). Organic coating on biochar explains its nutrient retention and stimulation of soil fertility. *Nature communications*, 8(1), 1089.
- Bonhot J, Harrison EZ. (2004). Testing Composts. Cornell Waste Management Institute. Updated 2015. 6 p.
- Woods End Research Laboratory (2005). Interpreting Waste & Compost Tests. Journal of the Woods End Research Laboratory, Vol 2. No 1.

An Illustrated Guide to Plant Bioassay Procedures

	1. Prepare soil for all treatments 2. Plant seeds 3. Top up moisture levels 4. Cover with humidity dome 5. Place on trays in growth chamber or greenhouse
	6. After two weeks, remove plants from growth environment 7. Count germinations in each pot and record
	8. Count number of fully developed secondary leaves and record 9. Count number of incipient secondary buds and record
	10. Cut all plants for each treatment at soil level and combine

	11. Place plants from each treatment in a separate mesh bag and label, then place on drying tray
	12. Dry plants for 24 hours at 105 degrees F in food dehydrator
	13. Weigh each treatment using a scale that is accurate to .01 grams

SAMPLE GERMINATION AND GROWTH TEST REPORT

Germination and Growth Test Report 12-17-16

Treatments:

DM – Don Morrison’s composted biochar (biochar chunks picked out of compost pile)

JL – John Livingston’s vermicompost (with biochar added to vermicompost bedding)

C – Control (Sunshine #4 potting mix)

Methods:

- 5 replicates of each treatment.
- Base is peat-perlite soil-less medium manufactured by Sunshine.
- Pots are 4” round pots with individual humidity domes.
- Control pots have 330g air-dry potting soil
- Treatment pots have 275g air-dry potting soil mixed with 60ml of amendment
- Each treatment mixed with soil and wet to squeeze test – 600 ml water
- Ten cucumber seeds planted in each pot with two tablespoons of plain soil on top.
- Humidity domes attached
- Treatments randomized on one greenhouse tray and placed in growth chamber for 2 weeks.
- At 2 weeks, remove from growth environment
- Count germination numbers
- Count secondary leaves (for reporting we combined fully developed leaves and leaf buds).
- Cut plants at root level and place in drying oven. After drying, biomass of each treatment is weighed with scale (MyWeigh Balance 601)

Results:

Treatment	Germination (%)	Secondary Leaves & Buds (count)	Biomass (grams)
DM	100	67	2.04
JL	84	57	1.87
C	98	41	1.30



Figure 1. Treatments from left to right: DM, JL, C.